

AD-A175 865

ANISOTROPIC AND SELECTIVE REACTIVE ION ETCHING OF SIC
IN CHF₃ AND OXYGE. (U) RENSSELAER POLYTECHNIC INST
TROY NY CENTER FOR INTEGRATED ELE. M PAN ET AL.
DEC 86 RPI/CIE/TR-15 N00014-81-K-0605

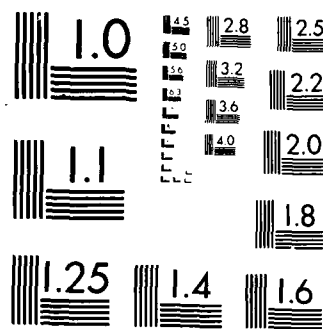
1/1

UNCLASSIFIED

F/G 13/8

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

To be published in Proceedings of the Materials Research
Society Symposium on Science and Technology
of Microfabrication

Boston, MA December 1986

ANISOTROPIC AND SELECTIVE REACTIVE ION ETCHING

OF SiC IN CHF_3 AND OXYGEN PLASMA

W-S. Pan and A.J. Steckl

Center for Integrated Electronics
Rensselaer Polytechnic Institute
Troy, N.Y. 12181

ABSTRACT

The use of CHF_3 plus oxygen plasma to achieve selective and anisotropic patterning of SiC thin films in the reactive ion etching (RIE) mode is reported. Experiments were performed using various levels of oxygen percentage (from zero to 90%), pressure (from 20 to 300 mTorr) and power (from 100W to 350W). Anisotropic etching of SiC with a vertical-to-lateral etch ratio in excess of 8:1 was measured for a $\text{CHF}_3 + 75\% \text{O}_2$ mixture at 20mT pressure and 200W RF power. Under these conditions, the SiC etch rate was measured to be 400 A/min and the selectivity over Si was approximately 2.2:1. The effect of the cathode DC potential and emission intensity of various species in the plasma on the SiC and Si etch rates is considered.

DTIC
ELECTE
DEC 16 1986
S D

DTIC FILE COPY

OFFICE OF NAVAL RESEARCH

Contract N00014-81-K-0605

Task No. NR 056-768

TECHNICAL REPORT NO. 15

ANISOTROPIC AND SELECTIVE REACTIVE ION ETCHING

OF SiC in CHF₃ and OXYGEN PLASMA

By

W -S. Pan and A.J. Steckl

Prepared for Publication in the Proceedings
of the Materials Research Society

Rensselaer Polytechnic Institute
Center for Integrated Electronics
Troy, NY 12181

Reproduction in whole or in part is permitted for
any purpose of the United States Government.

This document has been approved for public release
and sale; its distribution is unlimited.

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE									
1a REPORT SECURITY CLASSIFICATION		1b RESTRICTIVE MARKINGS							
UNCLASSIFIED									
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION/AVAILABILITY OF REPORT							
		Approved for public release; distribution unlimited							
2b DECLASSIFICATION/DOWNGRADING SCHEDULE		5 MONITORING ORGANIZATION REPORT NUMBER(S)							
		RPI/CIE/TR-15							
4a NAME OF PERFORMING ORGANIZATION		6b OFFICE SYMBOL		7a NAME OF MONITORING ORGANIZATION		5 MONITORING ORGANIZATION REPORT NUMBER(S)			
Center for Integrated Electronics		(if applicable)		Office of Naval Research					
6c ADDRESS (City, State, and ZIP Code)		7b ADDRESS (City, State, and ZIP Code)		8a NAME OF FUNDING/SPONSORING ORGANIZATION		9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
Troy, NY 12181				Chemistry Program		Contract W 00014-81-K-0605			
8b ADDRESS (City, State, and ZIP Code)		8d OFFICE SYMBOL		10 SOURCE OF FUNDING NUMBERS		11 TITLE (Include Security Classification)			
Chemistry Program		(if applicable)		PROGRAM ELEMENT NO. PROJECT NO. TASK NO. WORK UNIT ACCESSION NO.		Anisotropic and Selective Reactive Ion Etching of SiC in CHF ₃ and Oxygen Plasma			
Arlington, Virginia 22217				NE056-768					
12 PERSONAL AUTHOR(S) Wen-Sen Pan and Andrew J. Steckl									
13a TYPE OF REPORT		13b TIME COVERED		14 DATE OF REPORT (Year, Month, Day)		15 PAGE COUNT			
Interim Technical		FROM TO		December 1986		12			
16 SUPPLEMENTARY NOTES									
Prepared for publication in Proceedings of the Materials Research Society									
17		COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)					
FIELD		GROUP		Silicon carbide selectivity anisotropy					
				reactive ion etching					
19 ABSTRACT (Continue on reverse if necessary and identify by block number)									
<p>The use of CHF₃ plus oxygen plasma to achieve selective and anisotropic patterning of SiC thin films in the reactive ion etching (RIE) mode is reported. Experiments were performed using various levels of oxygen percentage (from zero to 90%), pressure (from 20 to 300 mTorr) and power (from 100 W to 350 W). Anisotropic etching of SiC with a vertical-to-lateral etch ratio in excess of 8:1 was measured for CHF₃ + 75% O₂ mixture at 20mT pressure and 200 W RF power. Under these conditions, the SiC etch rate was measured to be 400 Å/min and the selectivity over Si was approximately 2.2:1. The effect of the cathode DC potential and emission intensity of various species in the plasma on the SiC and Si etch rates is considered.</p>									
20 DISTRIBUTION/AVAILABILITY OF ABSTRACT		21 ABSTRACT SECURITY CLASSIFICATION							
<input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		unclassified							
22a NAME OF RESPONSIBLE INDIVIDUAL		22b TELEPHONE (Include Area Code)		22c OFFICE SYMBOL					
Dr. David L. Nelson		(202)696-4410							
DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted All other editions are obsolete									
SECURITY CLASSIFICATION OF THIS PAGE unclassified									

I. INTRODUCTION

Silicon carbide (SiC) has become a more attractive semiconductor material in recent years due to its wide band gap, high temperature stability, high breakdown electric field and high electron saturation velocity [1]. Various microelectronic applications for SiC have been reported, including light emitting diodes [2], high temperature transistors [3], dielectric isolation [4], heterojunction bipolar [5] and MOS transistors [6]. As the dimensions of VLSI devices are entering the sub-micron region, a selective and anisotropic etching process is essential in IC fabrication. In a previous publication [7], we have reported that SiC can be etched by RIE with fluorinated gases such as CF_4/O_2 , SF_6/He , SF_6/O_2 . The SiC etch rate was determined to be predominantly controlled by ion bombardment. This is in contrast to the etching of Si under the same conditions, where the fluorine species concentration was the rate limiting step. Our previous work indicated that useful SiC etch rates (300-600 Å/min) can be achieved with a variety of fluorinated gas mixtures.

In all previous cases examined, the SiC/Si etch rate ratio was considerably smaller than unity. However, in certain device applications one needs to etch the SiC layer selectively with respect to the Si substrate. In this paper, we report the results of our investigation to obtain a SiC/Si plasma etching rate ratio greater than one.

II. EXPERIMENTAL CONDITIONS

SiC thin films were deposited by RF (13.56 MHz) sputtering



Dist	Avail and/or Special
A-1	

<input checked="" type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

onto silicon substrates in a planar system (Veeco). A hot-pressed stoichiometric SiC composite target cathode (99.7% purity) was used at an RF power of 200W. After deposition, the films were furnace annealed at 1100°C in a nitrogen ambient for 30 minutes. N-type (4-6 ohm-cm) (100) Si wafers were used to determine the Si etch rate and oxidized silicon substrates (in steam at 1100°C) were used for SiO₂ etching. The etching experiments were carried out in a parallel plate reactor (Plasma Therm PK1241) equipped with a computer-controlled grating monochromator for measuring optical emission within the plasma. Emission spectra in the wavelength range between 200 and 800 nm were monitored through a quartz window placed on the sidewall of the chamber. The DC self-bias of the RF electrode was also monitored. The base pressure of system was less than 2.0×10^{-5} Torr. To determine the etch rate in various ambients, Al was used as a thin film mask since it is suitable for both low and high percentage of oxygen. The Al mask was subsequently removed by wet etching for step height determination by profilometer (Dektak). Samples with deeply etched patterns were used to observe the anisotropic etching phenomena by scanning electron microscopy (SEM : Nanometrics Cwickscan II). Auger electron spectroscopy (AES) was used to obtain composition versus depth profiles of both pre- and post- plasma etched SiC samples.

III. RESULTS

The etch rates were determined as a function of oxygen percentage of in CHF₃ + O₂ mixtures, RF power and pressure. In Fig. 1a, the SiC etch rate is shown as a function of oxygen

percentage (from 0% to 90%) in the CHF_3/O_2 mixture at a pressure of 20mTorr and a total flow rate of 20sccm. In Fig. 1b are shown the corresponding DC self-bias and the relative intensity of fluorine [F], hydrogen [H] and oxygen [O] emission at 703.7, 487 and 780 nm, respectively. The etch rates of Si and SiO_2 are found to be lower than SiC when the percentage of oxygen is higher than 35% and the etch rate of SiC reaches the maximum value, 420 A/min, at a level of 65% O_2 . Further increases in the oxygen percentage result in a decrease in the SiC etch rate. The Si etch rate reaches a plateau of approximately 300 A/min at oxygen percentages between 10% and 50%. For oxygen concentrations higher than 50%, the etch rate of Si decreases rapidly. The highest SiC to Si etch rate ratio is 2.2 at 75% O_2 , where the etch rates of SiC and Si are 400 A/min and 180 A/min, respectively. Fixing the oxygen composition at 75%, the pressure and power are varied to optimize the etching ratio. In Fig. 2 (a, b) the etch rate versus pressure (from 20 mT to 300 mT) is shown along with the DC self-bias and the emission line intensity of [F], [H] and [O] for an RF power of 200 W and a flow rate of 20 sccm. The oxygen and fluorine intensities at first increased rapidly with pressure (from 50 to 100 mTorr) and then tended to decrease slightly for higher pressure. The DC self-bias decreased monotonically with increasing pressure. While the etch rate of Si tended to follow the fluorine intensity, the etch rate of SiC appears to be determined by a combination of the DC bias and [O] intensity.

In Fig. 3 (a, b) the etch rate versus power is shown along with the corresponding DC self-bias and the emission intensity of

[F], [H] and [O] for the same 75% oxygen content and flow rate of 20 sccm but at a fixed pressure of 20 mT. The etch rate ratio of SiC to Si increases from 1.8 to 2.3 with power increasing from 100 W to 350 W. The etch rate of SiC ranges between 100 Å/min at 100W to 740 Å/min at 350W. The SiC etch rate is seen to increase with power approximately twice as fast as the Si etch rate. This is consistent with an [O] intensity increase with power which is two to three faster than the [F] increase.

The samples which were used to measure the etching anisotropy were etched in CHF_3 75% O_2 at 20 mT, 200 W, and 20 sccm. The vertical-lateral etch ratio is 8:1 for SiC and 4.5:1 for Si, as shown in the SEM microphotographs of Figs. 4, 5, 6, 7.

IV. DISCUSSION

The data obtained for the reactive ion etching of SiC in CHF_3/O_2 indicate that the etch rate of SiC is controlled by a combination of physical and chemical factors: (a) the DC self-bias; (b) the abundance of oxygen in the plasma. A few interesting aspects of this rather complicated process are discussed here. In the case where the oxygen percentage was varied (Fig. 1) the pressure and power were kept constant, resulting in a constant DC bias and a monotonically increasing [O] abundance. The SiC etch rate in this case appears to follow the [O] intensity curve up to 75% O_2 . For higher O_2 percentage (90% O_2), even though the [O] intensity still increases somewhat the SiC etch rate drops dramatically. This could be due to the fact that the Si etch rate is very low at this point thus presenting a surface barrier layer for SiC etching.

In the case where the oxygen percentage is fixed at 75% and the pressure is varied (Fig. 2), the DC bias decreases while the [0] intensity first increases dramatically with pressure (up to 100 mTorr) and then exhibits a slight decline. In this case, the two SiC etch rate determining factors have a somewhat competing effect. Initially, at low pressures (20-100 mTorr) the rapidly increasing [0] abundance overpowers the effect of the decreasing DC bias and results in a slight increase in the etch rate. However, for higher pressures (>100 mTorr) the [0] intensity is roughly constant and the effect of the decreasing DC bias dominates, thus resulting in a rapidly decreasing SiC etch rate.

By comparison, the Si etch rate appears to be predominantly controlled by the [F] intensity. Therefore, one can generally obtain a SiC/Si etch rate ratio larger than unity by reducing the [F] intensity and increasing the DC bias and [0] intensity. The [F] intensity can be depressed by changing the gas medium from CF_4 to CHF_3 and, of course, by increasing the oxygen percentage.

V. SUMMARY AND CONCLUSIONS

In summary, we have presented the first report of reactive ion etching of SiC at a rate higher than that of Si. For $\text{CHF}_3/75\% \text{ O}_2$, the SiC/Si etch ratio is 2.2. At the same time, highly anisotropic (8:1) etching of SiC was achieved under the same conditions.

The SiC etch rate appears to be controlled by a combination of physical (DC bias) and chemical (oxygen intensity) mechanisms.

ACKNOWLEDGMENT

The authors would like to acknowledge partial support for this work from the Office of Naval Research, under ONR contract No.N00014-81-K-0605.

- [1] J.D. Parsons, R.F. Bunshah and O.M. Stafsudd, 133, Solid State Technl. Nov. 1985.
- [2] S. Nishino, A. Ibaraki, H. Matsunami and T. Tanaka, Jpn. J. Appl. Phys., 19, L353 (1980).
- [3] W.V. Munch and P. Hoeck, Solid State Electron, 21, 479 (1978).
- [4] W.-J. Lu, A.J. Steckl, T.P. Chow and W. Katz, J. Electrochem. Soc. 131, 1907 (1984).
- [5] K. Sasaki, S. Jurukawa and M. M. Rahman, 249, 11.2, IEDM, 1985.
- [6] Y. Kondo, T. Takahashi, K. Ishii, Y. Hayashi, E. Sakuma, S. Misawa, H. Daimon, M. Yamanak and S. Yoshida, 404, Vol. EDL-7, No. 7, IEEE Electron Device Letters, July 1986.
- [7] J. Sugiura, W.-J. Lu, K.C. Cadien and A.J. Steckl, 349, B4 (1), J. Vac. Sci. Tecnol., Jan./Feb., 1986.
- [8] R.A.H. Heinecke, Solid State electron, 18, 1146 (1975).

Fig. 1 (a,b)

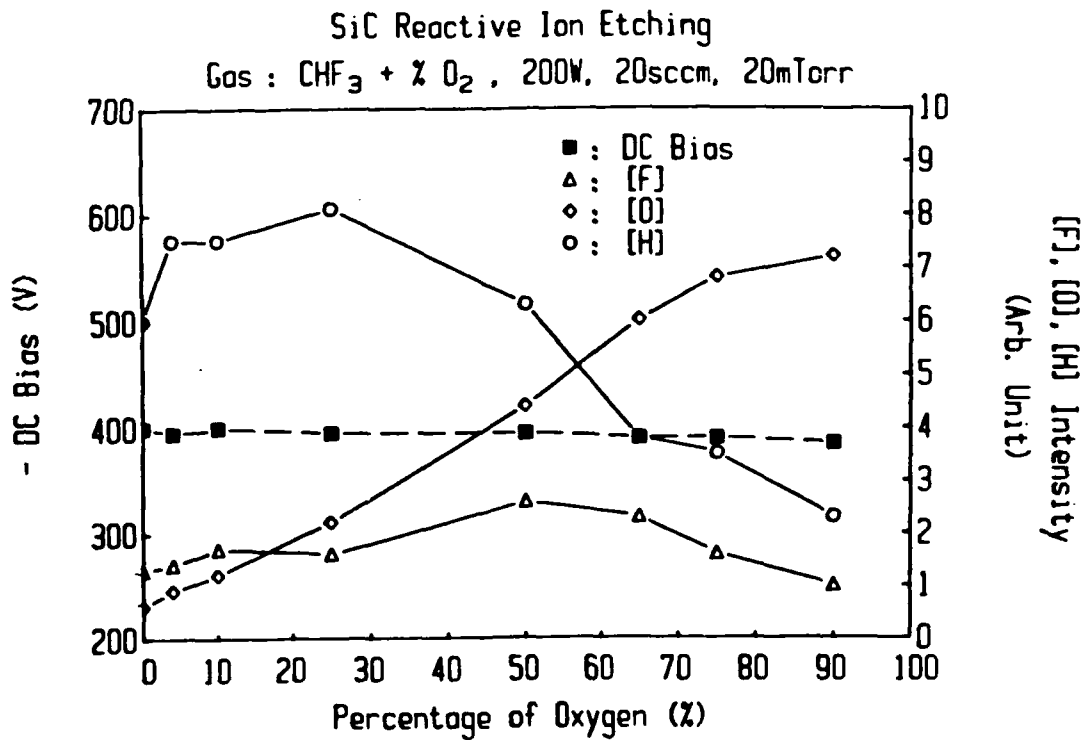
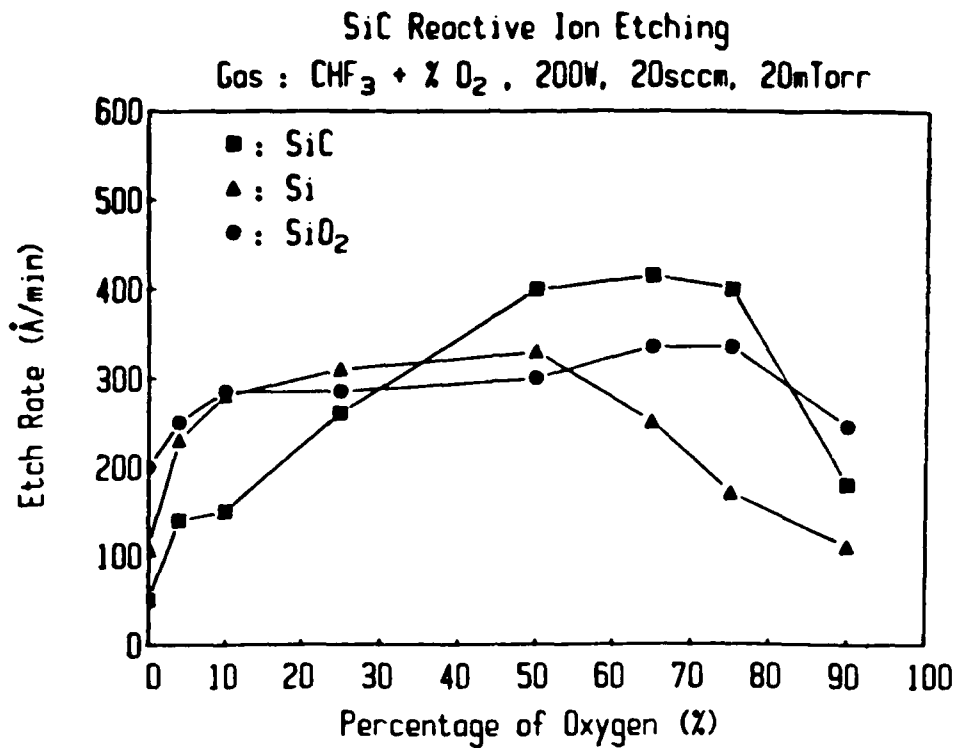


Fig. 2 (a,b)

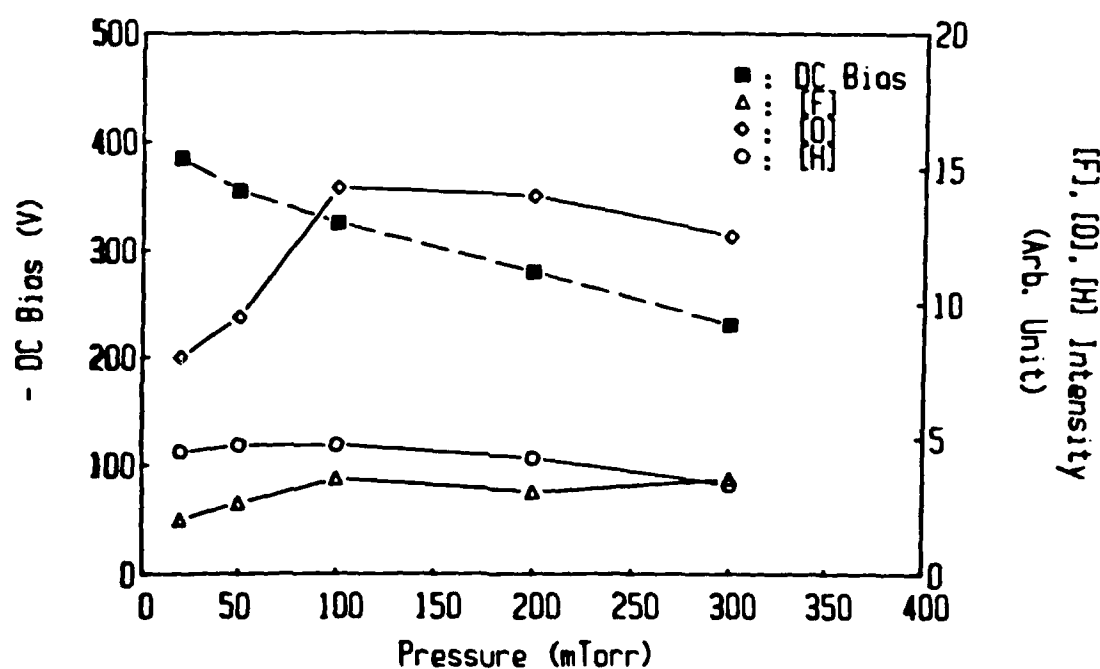
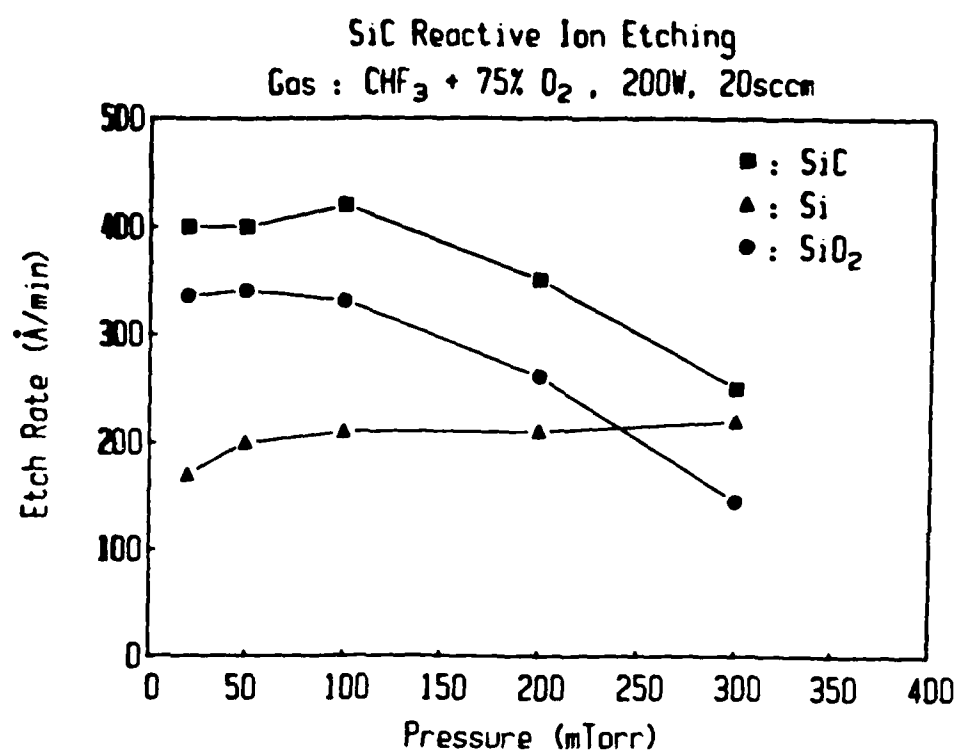


Fig. 3 (a,b)

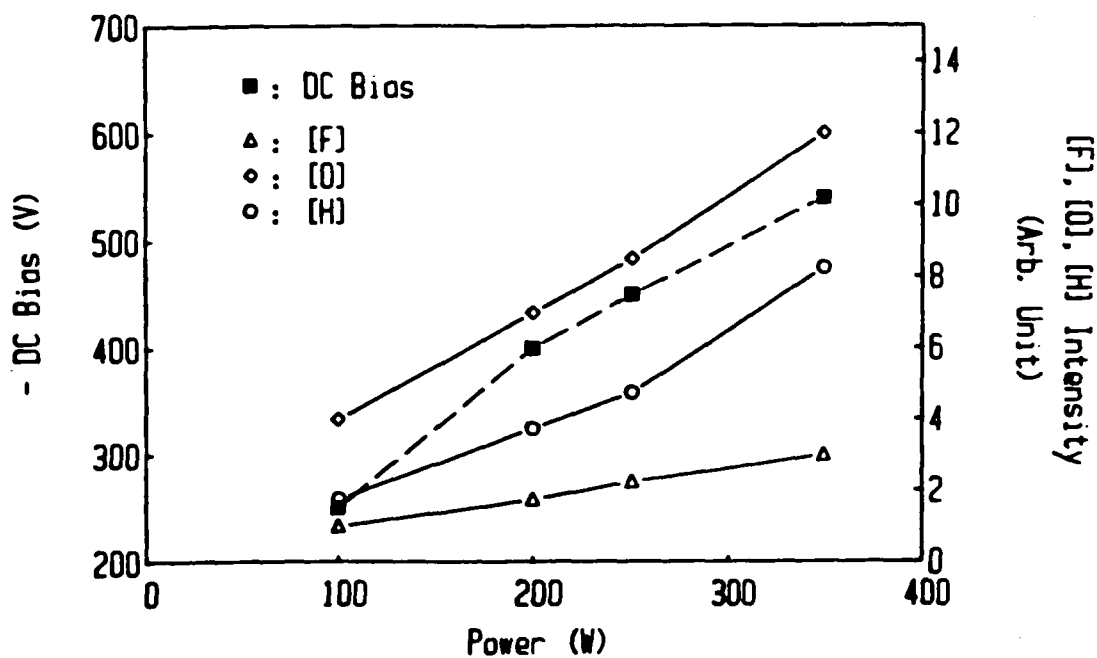
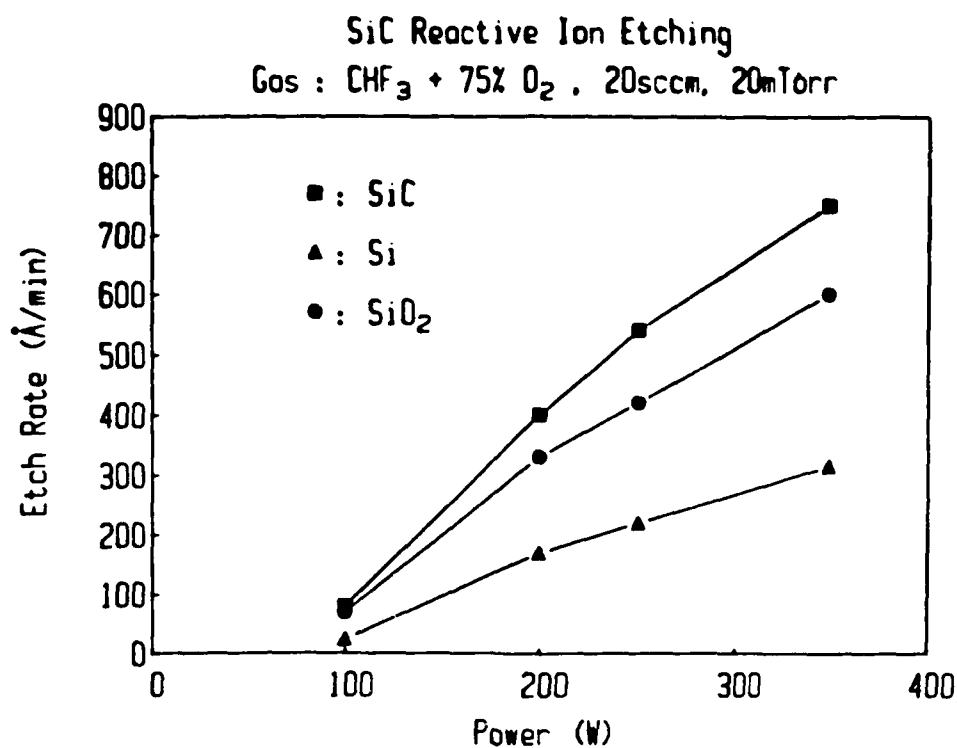


Fig. 4, 5

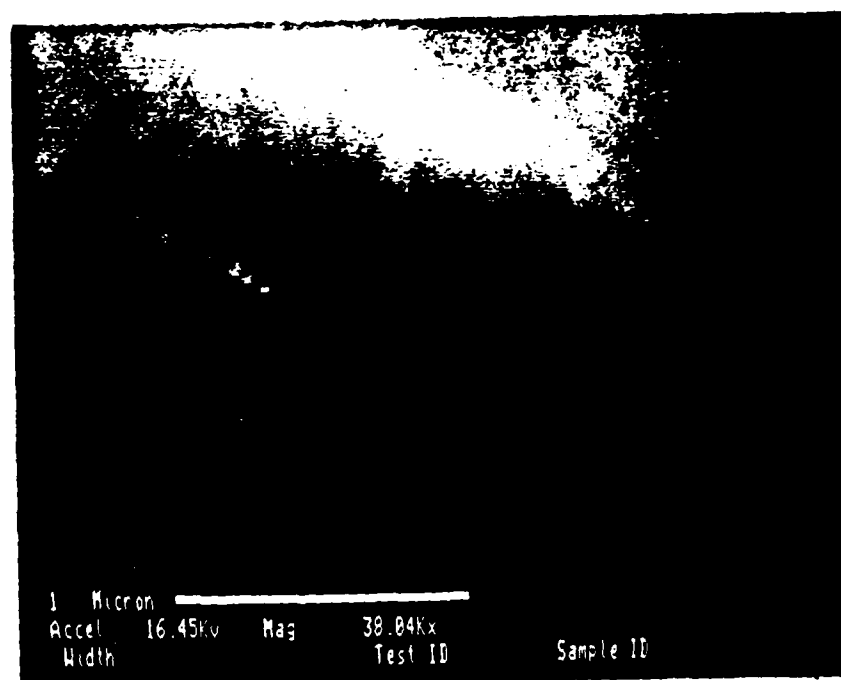
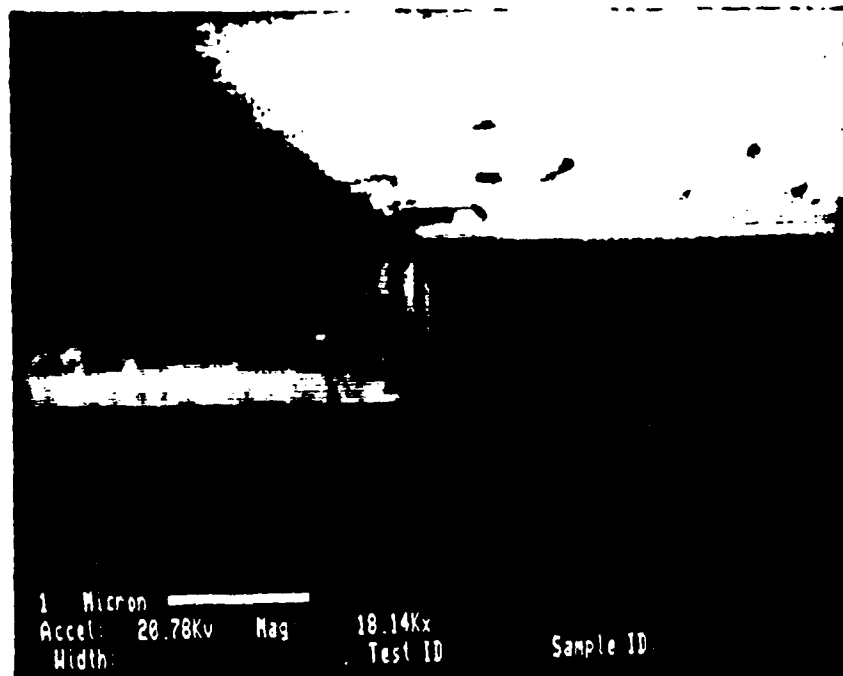
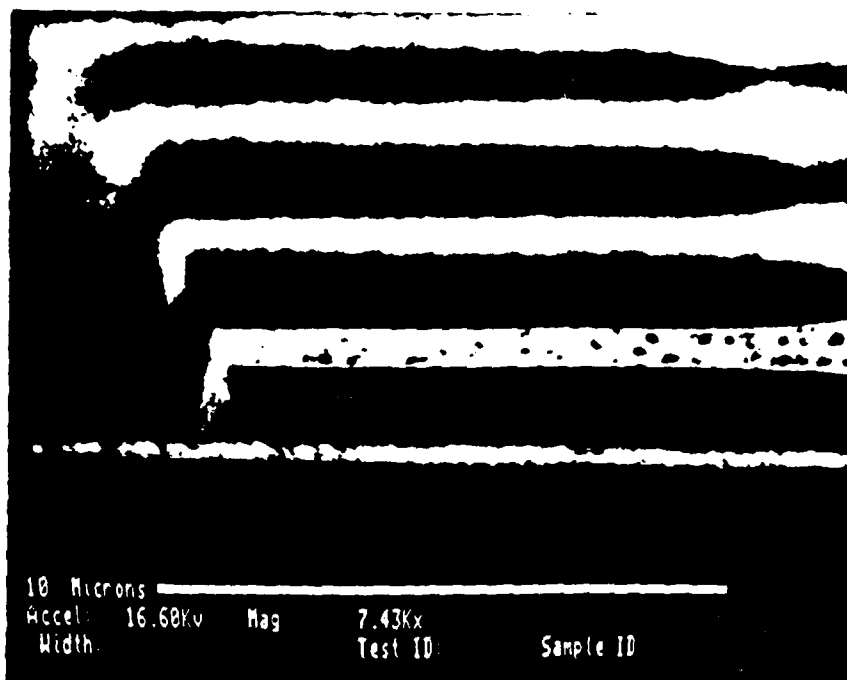


Fig. 6, 7



END

1-87

DTIC